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A PORTABLE COMBINATION DOSE-DOSERATE METER

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ADMINISTRATIVE INFORMATION

This report covers a facet of the work authorized during FY 1961 and FY 1962 by the Bureau of Ships under RDT&E Subproject S-F011 05 04, "Radiac Program," Task 6003, "Radiac Investigation." Details of this work are found in the U.S. Naval Radiological Defense Laboratory FY 1962 Technical Program as Program B-5, Problem 1, entitled "Radiac Component, Circuit and Systems Development," the objective of which is to devise advanced electronic circuits, circuit elements, and systems to meet current and future requirements of radiac instruments. Funds to support this work during FY 1962 were provided by the Bureau of Ships on Budget Project 50 Allotment 178.

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ABSTRACT

A battery-operated portable combination ratemeter-dosimeter has been developed which will measure gamma radiation rate from 0-1000 r/hr in three linear decade ranges. Simultaneously, the integrated dose may be read from a digital display whose range is 0-999.9 r. The least count on the digital register is 0.1 r. The rate may be read with an accuracy of less than ± 10 percent between -40 and +50°C. The integrated dose from Co^{60} isotope may be read to 0.1 r or ± 10 percent, whichever is greater, from -40 to +50°C. Battery life, using two C size nickel-cadmium rechargeable cells is in excess of 40 hr per charge. Package weight, including battery, is less than 3 lb, and size is 4 by 4 by 7 in.

SUMMARY

The Problem: To develop a lightweight, portable, battery-operated radiac which will measure gamma intensities between 0 and 1000 r/hr and, in addition, totalize the dose received up to 1000 r on a digital register whose least count is 0.1 r. The rate and dose-measuring functions should be accurate within ±10 percent of the true value, between -40 and +50°C.

The Findings: A combination ratemeter-dosimeter has been developed which uses the recycling detector as the input to a rate-measuring circuit, and to a separate dose-measuring system. This instrument will measure gamma intensities on three linear scales of 0-10, 0-100, and 0-1000 r/hr. Also, it will totalize dose received in 0.1 r increments up to 1000 r. Accuracy of the rate function, when exposed to Co^{60} from the front, is ±10 percent of the true value, and of the dosimeter ±10% or 0.1 r, whichever is greater, in the temperature range -40 to +50°C.

The unit is powered by two size C nickel-cadmium rechargeable cells which will operate the instrument in excess of 40 hr before recharging is necessary. The package is 4 by 4 by 7 in. in size, and weighs less than 3 pounds, including battery.

INTRODUCTION

Based on the development of a recycling ratemeter[1] and a recycling dosimeter,[2] work was started on the design of a radiac having the dual capability of measuring either dose or doserate (intensity), or both simultaneously. The instrument described in this report is the result. With this one radiac, the small ship, the independent tactical unit, or the command post will have much of the necessary dose and doserate information readily available for decision making.

OUTLINE OF INVESTIGATION ON RDGI-1

Object

To demonstrate the feasibility of combining the circuit principles of the recycling ratemeter and the alarm dosimeter and producing an instrument having a ratemeter capability in the range of 0-10, 100, and 1000 r/hr, as well as a dosimeter capability whose least count is 0.1 r, with a totalizing capability of 1000 r.

RECYCLING RADIATION DETECTION SYSTEMS

Background

The ion chamber is a sensitive, linear, wide-range detector of gamma radiation, and many circuits have been devised using the ion chamber for the basic sensing element. Because of the high impedance circuitry necessary to measure the minute currents generated by this detector, vacuum tube electrometers are used either single-ended or in

a balanced configuration to amplify the currents to usable values. Usually a form of balancing system is necessary to reset the zero of the meter, especially on the more sensitive ranges, or to compensate for aging of the tubes and batteries. To simplify the operation of the ion chamber detector and to save on the power requirements of such a device, a program was established to develop a system which would be economical, reliable, and uncomplicated in operation. A modification of the recycling ion chamber detection system[3] is the result.

The Recycling Detector

Fig. 1 is a simplified schematic drawing of the basic recycling system. Radiation falling on ion chamber, I, causes the triode V to come out of cutoff and increase its transconductance until the grid is permitted to conduct. An increase in loop gain ensues which causes the transistor Q blocking oscillator to block on recharging C, the parallel combination of the chamber and tube capacitances until the tube is once again cut off and ready to measure radiation. A more complete description of the special circuit used in the RDGI-1 is presented later in this report.

By increasing C, the recycling detector may be made to recycle more slowly and, conversely, it will recycle faster with a smaller value. The value of C alone can thus determine whether the unit will operate as a rate meter (small C) or as a dosimeter (large C).

A Combination System

From the foregoing description of the recycling detector, it is evident that one needs two distinct detector circuits; one of low chamber capacitance to achieve the high repetition rates necessary for good ratemeter operation, and one of large chamber capacitance to recycle once for each 0.1 r of dose received. As an alternative to using two detectors, one may use a single detector of highest practical sensitivity (lowest chamber capacitance), which will give usable repetition rates for 1 r/hr and greater. This will be approximately 0.3 mr/cycle with the detectors used at this Laboratory. By storing a number of such pulses in a predetermined counter, the equivalent of 0.1 r will be accumulated. The last pulse will generate one output pulse in the counter which may be used to trigger a register drive circuit and advance the register by 0.1 r. In practice this is done by a commercially available counter.*[4] Figure 2 shows in block form the method of operation of the combination system.

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*General Time Corporation "Incremag" Counter, Model IM-20p-2j.

FUNCTIONAL OPERATION OF THE RDGI-1 COMBINATION DOSE-DOSERATE METER

It is intended that this instrument shall use the same type of ion chamber detector and blocking oscillator circuitry as the circuit in reference 2, which recycles each time a predetermined dose has been accumulated (nominally 0.3 to 0.5 mr). A moderate tolerance ($\pm$0.2 mr) is possible by adjusting the counter circuitry in the dosimeter section, which is discussed later in this report. The circuit described in ref. 2 has been revised extensively to ensure constant repetition rate under various environments, at constant radiation level. This is necessary in order to relate the count rate to radiation intensity, and simultaneously to integrate the pulses into an accurate accumulated dose. The dose accumulated per cycle of the detector circuit must remain constant under all conditions of battery voltage and temperature if a true dose is to be registered by the dosimeter section. Having attained a pulse repetition frequency (prf) which is proportional to radiation intensity, we may use the pulses in the following two ways:

1. The pulses may be passed through a pulse shaper which will drive a rate-metering circuit. Range changing may be accomplished by suitable switching circuitry.

2. Simultaneously, the pulses will be differentiated and used to trigger a pulse-counting circuit whose function is to divide the pulse rate by some factor between 144 and 333, which will in effect cause one pulse at the output end of the counting string to be the equivalent of 0.1 r dose accumulated by the detector section. The output pulse from the count divider is used to advance the dose register by the equivalent of 0.1 r, or one unit in the tenths counting wheel. Four wheels are used on the dose register to represent 100's, 10's, units, and tenths. In this manner the numbers appearing on the register may be read directly in dose, to the nearest 1/10 r. Provisions are made to reset the register to zero when necessary. Also, while not incorporated in the experimental model, it is possible to modify the register so that the unit will give an audible or visual alarm on the accumulation of any predetermined dose.

Physical Description

The experimental model has a physical size of 4 by 7 by 4 in. This may be decreased in volume by about 40 percent with careful packaging. Visible on the top are the dose register, the rate meter, and the operating switch. There is only one operating control available to the operator, the combination off-on, range, function, and battery test

switch. This minimizes confusion and increases the reliability of the device.

Internally, there are two subchassis which separate the functions of rate and dose measurement. One chassis has the rate counting and detector circuitry. On the other chassis there are the count divider and register drive circuits, and the high voltage power supply which supplies polarizing potential for the ion chamber. The battery is mounted between the two chassis and is readily accessible for recharging or changing. Figures 3 and 4 show external and internal details of the construction. The weight of this instrument, including batteries, is 2.8 lb.

Fundamentals of Electrical Operation

Detector-Ratemeter Chassis. Figure 5 is an operational schematic of the RDGI-1 ratemeter circuit with actual values replaced by symbols for purposes of clarity in the following discussion of the electrical operation of the instrument.

Since the RDGI-1 performs two separate functions which are somewhat interdependent, it may be well to discuss the ratemeter-detector circuit first. The three principal elements of the detector circuit are V, D_1, and Q_1. Operation of the recycling detector may be analyzed as follows:

Assuming that the system has just cycled, C_1 will have a charge on it which will negatively bias the plate, P, with respect to G. This will cut off V, and no current will flow in the grid circuit. At this time the potential on the cathode of the diode, D_1, will be 0 v with respect to ground. R_4 is adjusted under these conditions to be -0.8 v, approximately. This voltage back-biases D_1, which then appears to be a very high impedance. The trigger voltage across winding II of T_1 is thus prevented from appearing at the base of Q_1. The feedback path for the trigger signal is from pin 6 of winding II,T_1, through C_3, D_1, and C_4, to the base, out the emitter through R_7 to the center tap of I,T_1, thence to ground, where it returns to pin 5 through the high voltage filter capacitor. As the charge is dissipated on C_1 because of the presence of radiation, the plate, P, becomes less negative. The grid then draws current, causing a potential drop across R_1. When the drop exceeds -0.8 v, D_1 becomes forward biased and appears as a very low impedance. Feedback signal from II,T_1, will then appear at the base of Q_1 and oscillations will rapidly build up. At this time the power feedback loop from pin 4,T_1 through D_2, takes over and blocks on the oscillator for about 15 μsec. After this interval the transformer

saturates, feedback ceases, and the field built up in T_1 collapses. A flyback or reverse polarity voltage then appears at pin 6,T_1 which is positive in sign. This is transferred to P through C_1. P is thus forced momentarily positive with respect to the filament, permitting electrons to flow to P and charge C_1. When the flyback interval ceases, P is left charged negatively as at the start of the description, D_1 is back-biased again and no more oscillations will occur until another increment of dose has been measured by I. As discussed previously, during the conduction or on time of the blocking oscillator, a negative voltage appears at pin 4,T_1. This is used for power feedback for the oscillator through D_2. Also, a part of the voltage is available to bias the base of Q_2 negatively. Inspection of the diagram will show that, normally, base Q_2 is positive 1.35 v with respect to the emitter because of the manner in which the emitter is returned to the battery. During the time when no pulse occurs, Q_2 is cut off and no meter current flows in M, the rate-indicating meter. By using Q_2 as a switch, large currents are available in the metering circuit and the effect of I_{co} of the transistor is virtually eliminated. The effects of temperature and battery condition on this circuit and the detector circuit will be discussed in another part of this report. The ratemeter current-measuring circuit is a constant charge type in which a condenser is allowed to charge fully during the on time of the blocking oscillator pulse. In the worst case the condenser is charged up to greater than 99 percent of maximum before the pulse is half completed. This method of metering is sensitive to battery voltage changes, but the terminal voltage of the Ni-Cd battery varies less than 20 percent from full charge to depletion, and is relatively flat during 90 percent of its discharge life.

Since the charge transferred to the meter per pulse is a function of the condenser value, other values remaining constant, range changing may be accomplished by decading the capacitors, and using appropriate switching circuitry. An advantage of range changing in this manner is economy of meter current. For all ranges the maximum average current through the metering transistor is the full scale value of the meter, 20 μamp. No current is wasted in shunts.

Count Divider-Dosimeter Chassis. The function of the count divider-dosimeter chassis, Fig. 6, is to integrate the pulses from the ratemeter section and to actuate the dose register when a predetermined dose, 0.1 r, has been received. To accomplish this, a commercially made counter was used. This unit is supplied by the manufacturer in single or multiple stages, each stage being factory set to give any pulse ratio from 1:1 to 16:1. With the present version of ion chamber, which has a maximum sensitivity of 0.3 to 0.5 mr/count, count ratios of 333 to 200 are needed. It is necessary to make some compromise between the most

sensitive ion chamber and the counting ratio of the pulse counter, since a more sensitive ion chamber will entail a greater counting ratio at more expense. However, too small a count ratio, with corresponding lowered sensitivity of the ion chamber will result in a jumpy ratemeter reading. A practical minimum pulse rate for a metering circuit is about 5 pulses per second, corresponding to full scale on the meter. This pulse rate gives ion chamber sensitivities of approximately 0.5 mr and count ratios as stated. These values are readily achieved and represent realistic numbers for which to strive.

The output pulses from the count divider are used to trigger a blocking oscillator, Q_3, which is normally off. The oscillator is triggered on and remains on for about 25 ms. At the same time, the voltage from the emitter of Q_3 is used to turn on a second transistor, Q_4, which acts as a switch in the register magnet circuit. In this manner the register is advanced every 0.1 r to a total of 999.9 r.

Power Supply. The high voltage power supply[5] is used only to supply the polarizing potential to the ion chamber. The current drain on the system is less than 1/10 μampere at 1000 r/hr; however, the supply can sustain drains up to 1 μampere with less than 30 percent drop in terminal voltage. Operation of the blocking oscillator is maintained by R_{13} which serves to dissipate the charge developed across C_{10} during the conduction part of the cycle. R_{13} also serves to drive the bias on the base of Q_5 into the high beta region under all conditions of temperature, increasing its reliability. High voltage is developed in winding II,T_3 during the flyback part of the cycle. This voltage may reach a higher value than the required 135 v, but D_4 is chosen as a type having inverse breakdown ratings between 100 and 200 v. The exact value is not critical as long as it remains constant. Thus, even though the voltage may go higher momentarily, it will be clamped to the zener or inverse breakdown value of the diode. This will occur as long as the battery has enough life to drive the voltage over the zener point. In this manner the voltage of the ion chamber is maintained at a constant value.

OPERATIONAL TESTS

Effects of Temperature and Environment

Recycling Detector. In the recycling detector, the main temperature

sensitive component is the transistor, Q_1. The collector cutoff current in Q_1 varies with temperature as shown in Fig. 7. The current gain, or Beta, of Q_1 varies with emitter current as shown in Fig. 8. It may be seen that there is a broad maximum of reasonably constant β over a wide range of emitter current between approximately 1 and 30 ma. Since the effect of temperature is to change the emitter current and also the β of the transistor, a suitable compromise was effected by biasing Q_1 to about 2 or 3 ma. At this point the gain of the blocking oscillator was adequately constant over the temperature range of interest. With no temperature compensation at all the response of the dose-measuring function is as shown in Fig. 9. For dose measurements it is necessary that the repetition rate of the recycling detector, under constant irradiation, remain the same for all temperatures of interest. The effect of variation of transistor gain with temperature is evident. To achieve a flat response a thermistor network was inserted at the output of the ion chamber. The response of the recycling detector is then as shown in Fig. 10. From a median at 30°C the repetition rate is constant within ±8 percent.

Ratemeter Circuit. Variations in the output of the ratemeter circuit are minimized by using the metering transistor, Q_2, as a switch. During the on time of the blocking oscillator in the recycling detector, Q_2 is overdriven to insure saturation at all times while it is in conduction. The saturation voltage is very small and relatively constant for changes in temperature, and the change in collector cut-off current with temperature is small compared to the total current flowing when the transistor is in saturation. The metering circuit is of the constant charge type in which the charging time of the integration condenser is small compared to the on time of the blocking oscillator. Thus it is only necessary that the condenser become fully charged each time. If the saturation resistance of the transistor, Q_2, changes with temperature, there is no effect as long as the condenser is still able to acquire a full charge. In practice the metering circuit has proved to be extremely stable with respect to temperature. One difficulty at first experienced in the use of germanium transistors was that a small quiescent current between 2 and 10 μa was present at all times, and varied with temperature. This is much less in silicon types. However, it was possible to use a germanium type for Q_2 by returning the emitter to a point more negative than the base. The quiescent current was then reduced to negligible proportions. Figure 11 shows a typical response curve of the ratemeter circuit, normalized to 30°C. The maximum difference between highest and lowest readings is 17 percent, and varies less than 5 percent between -50 and +30°C.

High Voltage Power Supply. The power supply was designed to supply

at least 135 v DC to the outer shell of the ion chamber at all temperatures of interest. Slow changes of DC bias to the chamber have little effect on the rate of the recycling detector. The variation in output voltage for the power supply is shown graphically in Fig. 12. In the event that additional regulation is necessary, the rectifying diode, D_4, could be selected to have a reverse or zener point breakdown in the region of 135 v. This will maintain a constant voltage, with adequate stability for this instrument, at all temperatures between -50 and +50°C.

Battery Life and Capacity. The battery used in the RDGI-1 is a pair of size C nickel-cadmium rechargeable cells. These cells have adequate capacity at all temperatures to operate the instrument in excess of 40 hr on one charge.

The constant 10 ma drain of the vacuum tube in the ion chamber produces an unequal load distribution on the battery, causing one of the cells to discharge approximately twice as rapidly as the other. Without taking this into consideration, the system will operate for approximately 45 hr. After this time one of the cells will be discharged, and the other will be approximately half discharged. The per charge operating life of the instrument, and the usefulness of the battery can be increased if the cells are interchanged after approximately 30 hr. The increase in battery life per charge is then an additional 15 hr, or a total of 60 hr compared to 45, if the cells are not interchanged.

Other Component Considerations

The "Incremag"* counter is a commercial item which was not designed to meet the temperature range of interest. According to the manufacturer, it will operate from +50 to -10°C. This counter has at times been operated successfully at -50°C in test runs. It has been determined that the register drive circuit stopped first at low temperatures. Recent correspondence with the manufacturer of this counter reveals that he may be able to make a silicon transistor version of the counter described herein which will operate reliably over the temperature range of -50 to +50°C. Their decision on this matter was not available at the time this report was published.

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*Product of General Time Corporation.

CONCLUSIONS

The successful design of the NRDL model RDGI-1 Combination Ratemeter-Dosimeter has demonstrated the feasibility of producing a single instrument which combines the functions of dosimeter and ratemeter with a minimum of redundancy. The RDGI-1 will indicate the true doserate within ± 10 percent between -50 and $+50^{\circ}$C. The integrated dose may be measured with an accuracy of ± 10 percent for the temperature range of -50 to $+50^{\circ}$C. While not incorporated in the experimental model, it is possible to provide an alarm which will sound when any predetermined dose or doserate is exceeded.

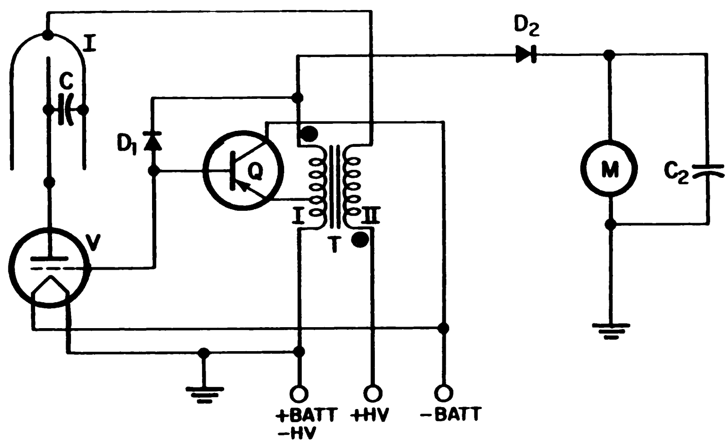

Fig. 1 Basic Recycling System

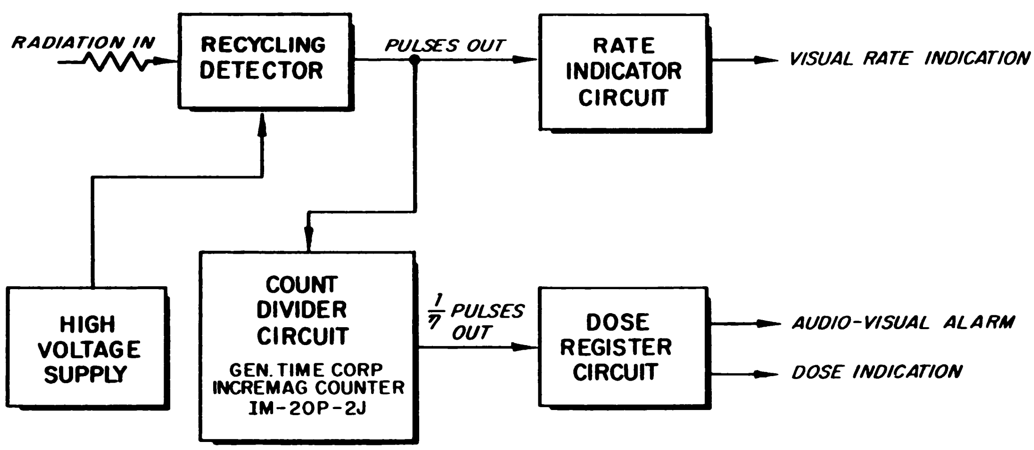

Fig. 2 Block Diagram of Combination Recycling Dose-Doserate Meter RDGI-1

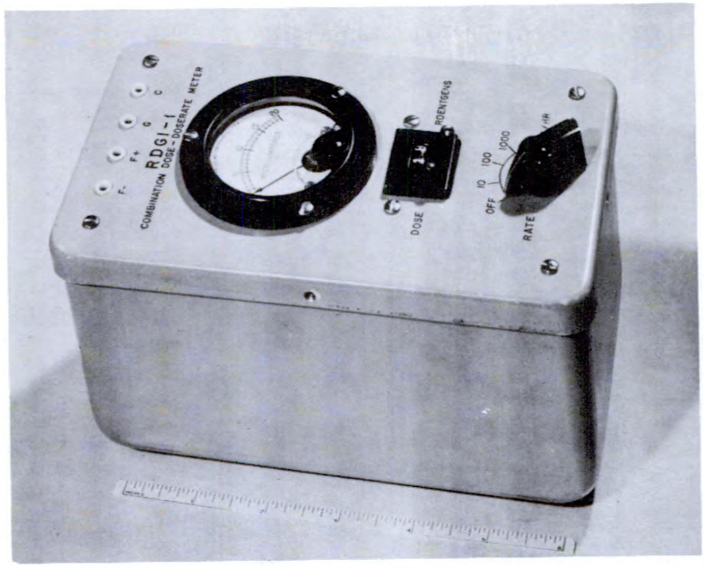

Fig. 3. External View of RDGI-1

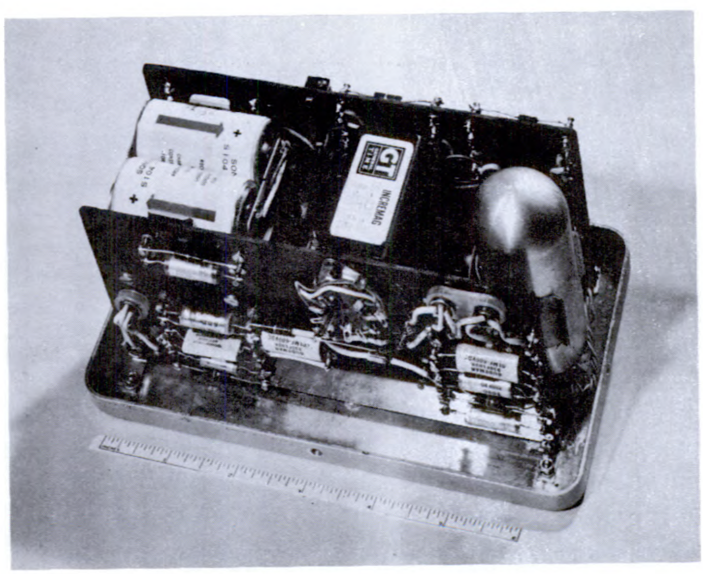

Fig. 4. Internal View of RDGI-1

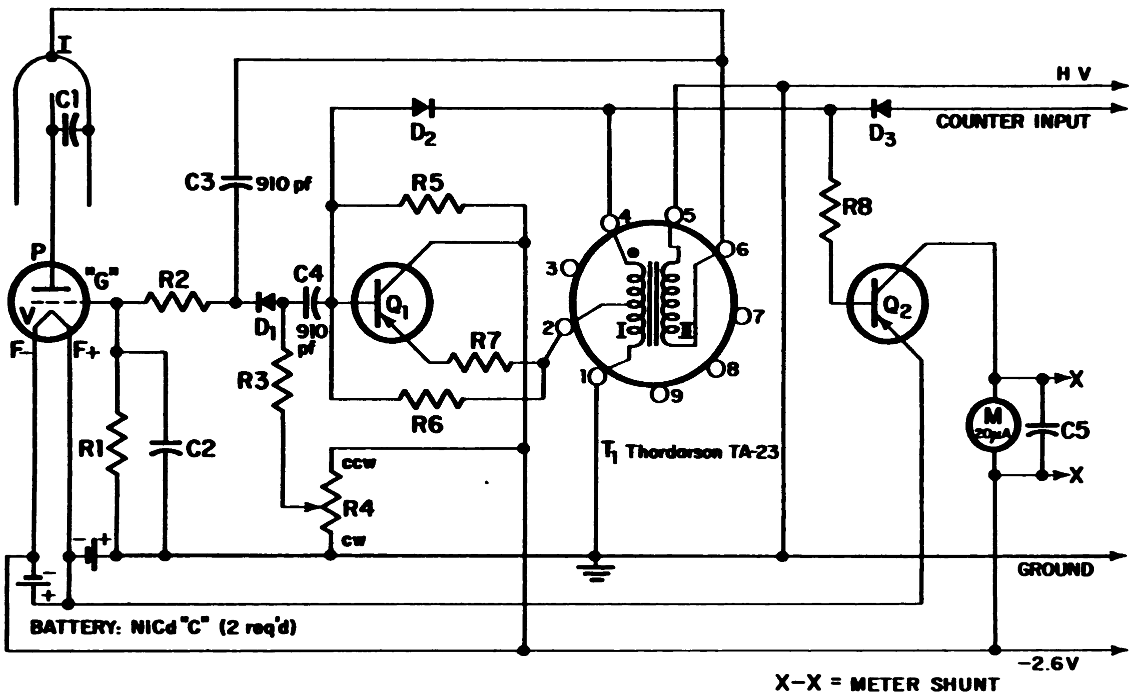

Fig. 5 RDGI-1 Ratemeter Chassis Schematic Diagram

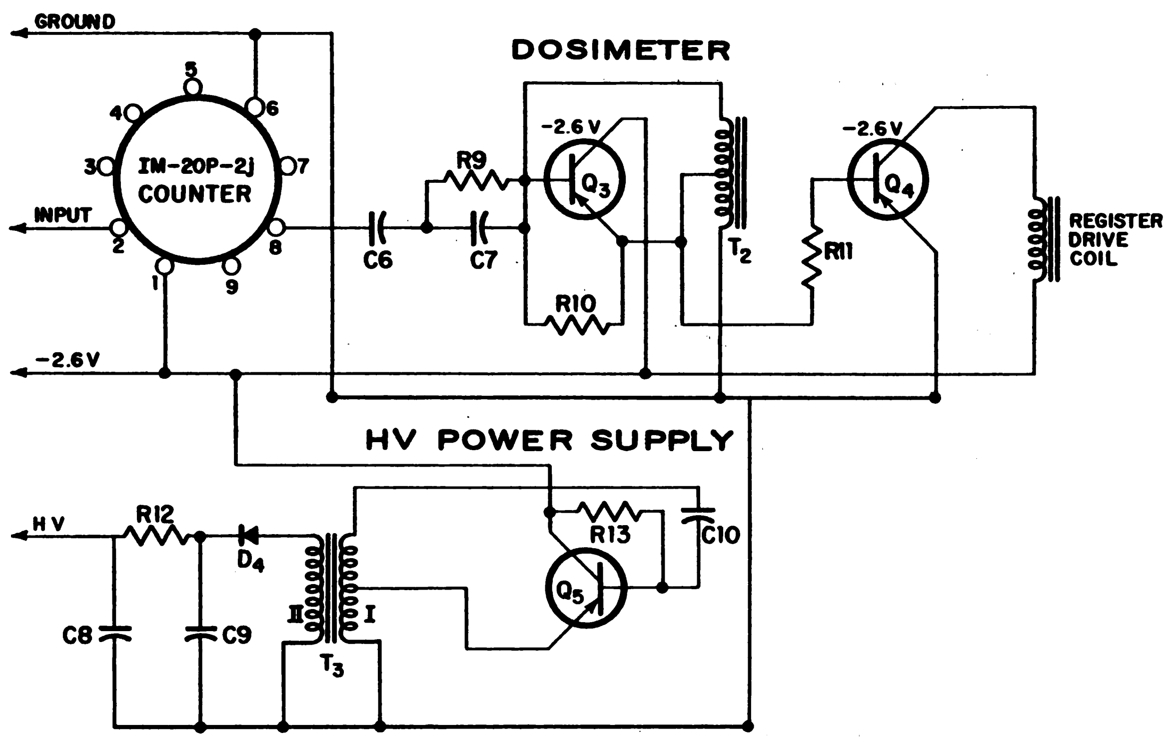

Fig. 6 Count Divider-Dosimeter Chassis Schematic Diagram

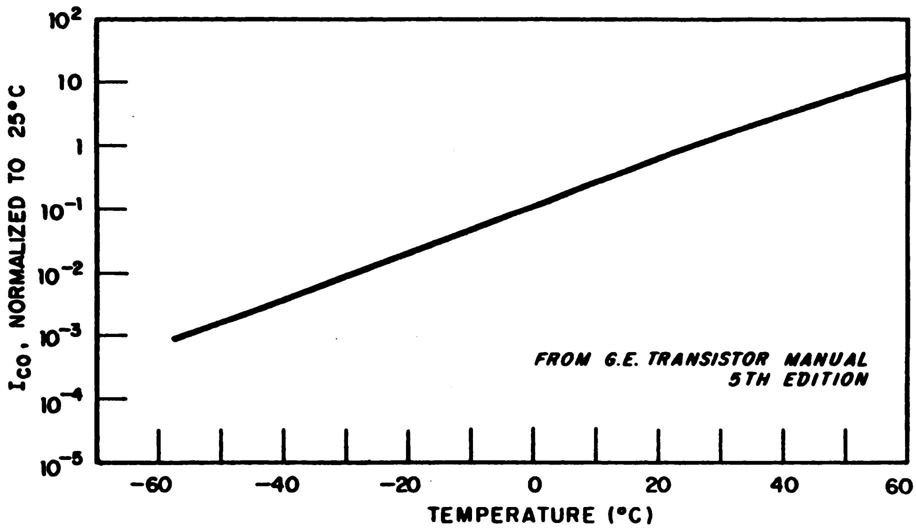

Fig. 7 Typical Transistor, Collector Cut-off Current vs. Temperature

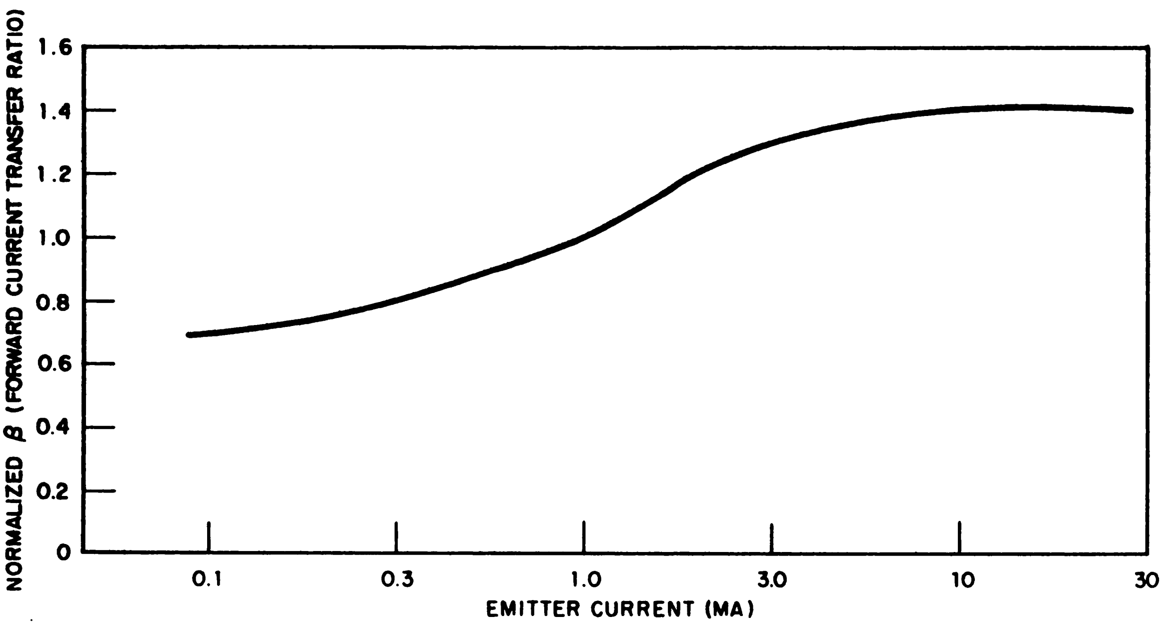

Fig. 8 Typical Transistor, β vs. Emitter Current

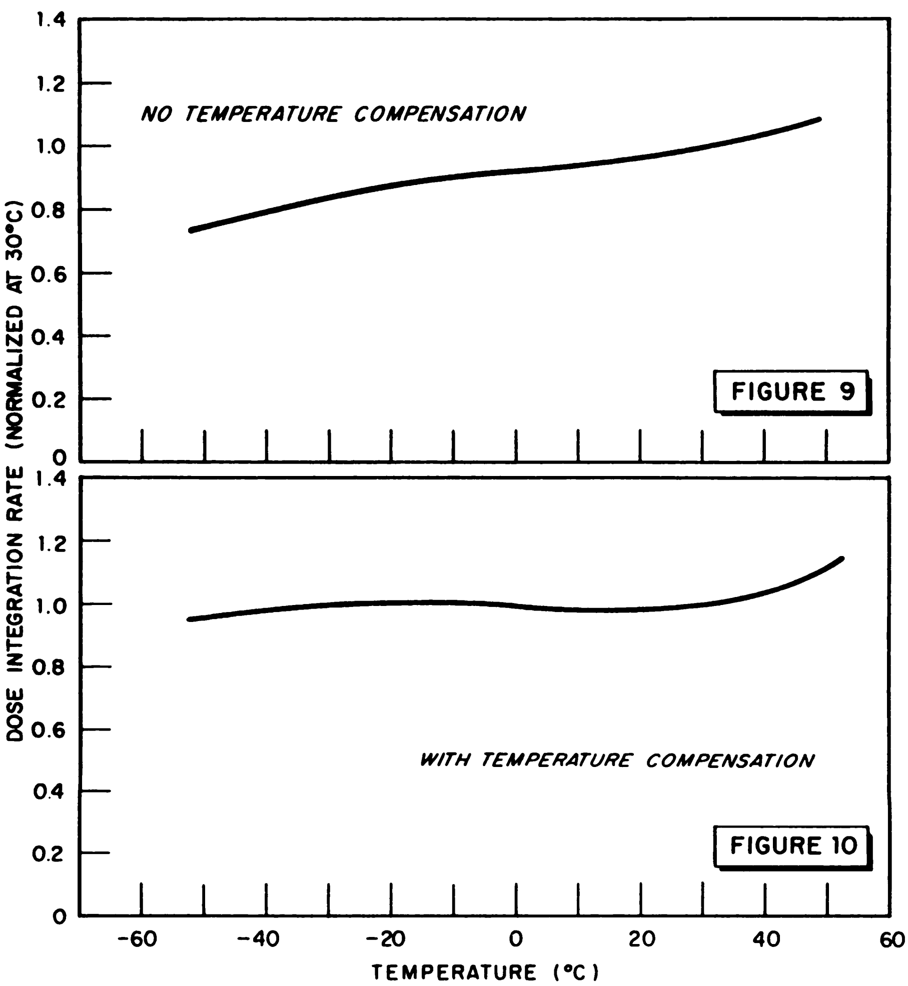

Fig. 9 Dose Integration Rate vs. Temperature Under Constant Level Irradiation, No Temperature Compensation

Fig. 10 Dose Integration Rate vs. Temperature Under Constant Level Irradiation, with Temperature Compensation

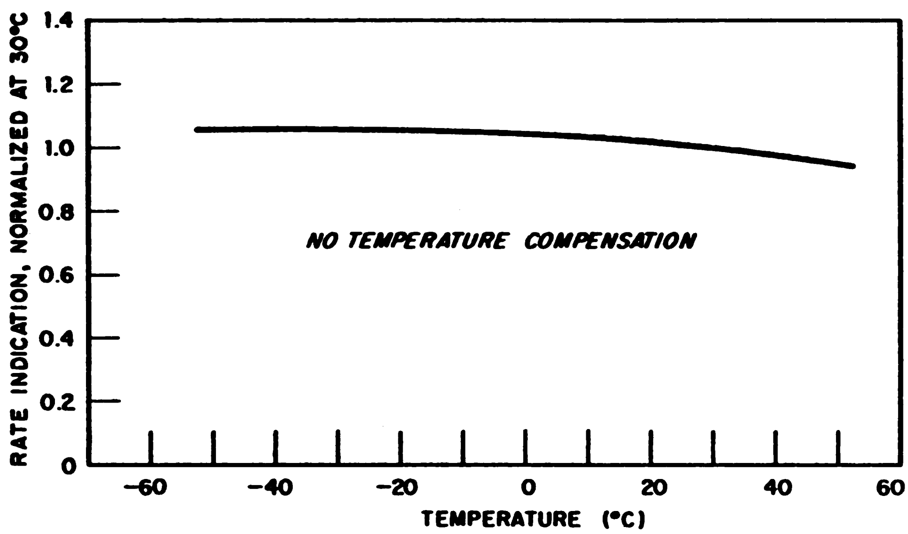

Fig. 11 Ratemeter Indication vs. Temperature Under Constant Level Irradiation, No Temperature Compensation

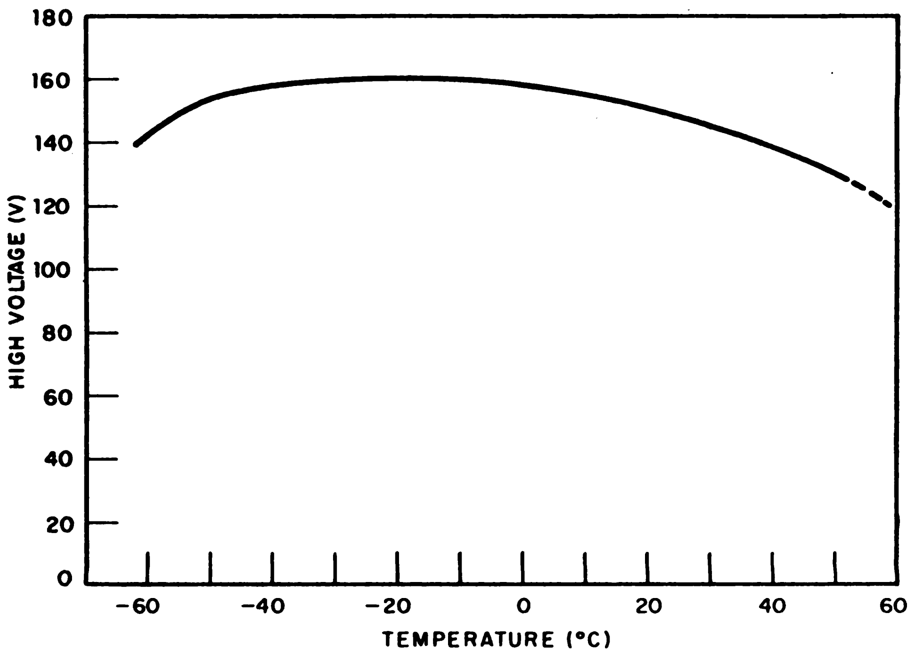

Fig. 12 High Voltage Power Supply, Voltage vs. Temperature

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63	Director, Walter Reed Army Medical Center
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182	Edgerton, Germeshausen and Grier, Inc., Las Vegas
183	Franklin Institute of Pennsylvania
184	General Atomic Division
185-186	General Electric Company (ANPD)
187-190	General Electric Company, Richland
191	General Electric Company, St. Petersburg
192	General Nuclear Engineering Corporation
193	Gibbs and Cox, Inc.
194	Glasstone, Samuel
195	Goodyear Atomic Corporation
196	Hawaii Marine Laboratory
197	Hughes Aircraft Company, Culver City
198	Iowa State University
199	Jet Propulsion Laboratory
200-201	Knolls Atomic Power Laboratory
202	Lockheed Aircraft Corporation

203-204	Los Alamos Scientific Laboratory (Library)
205	Lovelace Foundation
206	Maritime Administration
207	Martin Company
208-209	Midwestern Universities Research Association
210	Mound Laboratory
211	NASA, Lewis Research Center
212-213	NASA, Scientific and Technical Information Facility
214	National Bureau of Standards (Library)
215	National Bureau of Standards (Taylor)
216	National Lead Company of Ohio
217	New Brunswick Area Office
218	New York Operations Office
219	New York University (Eisenbud)
220	Nuclear Materials and Equipment Corporation
221	Nuclear Metals, Inc.
222	Oak Ridge Institute of Nuclear Studies
223	Patent Branch, Washington
224-227	Phillips Petroleum Company
228	Power Reactor Development Company
229-230	Pratt and Whitney Aircraft Division
231	Princeton University (White)
232	Public Health Service, Las Vegas
233	Public Health Service, Montgomery
234-235	Public Health Service, Washington
236	Rensselaer Polytechnic Institute
237-238	Sandia Corporation, Albuquerque
239	Sandia Corporation, Livermore
240	Stanford University (SLAC)
241	States Marine Lines, Inc.
242	Sylvania Electric Products, Inc.
243	Tennessee Valley Authority
244-245	Union Carbide Nuclear Company (ORGDP)
246-251	Union Carbide Nuclear Company (ORNL)
252	Union Carbide Nuclear Company (Paducah Plant)
253	United Nuclear Corporation (NDA)
254-256	U.S. Coast and Geodetic Survey, Washington
257	U.S. Geological Survey, Denver
258	U.S. Geological Survey, Menlo Park
259	U.S. Geological Survey, Naval Gun Factory
260	U.S. Geological Survey, Washington
261-262	University of California Lawrence Radiation Lab., Berkeley
263-264	University of California Lawrence Radiation Lab., Livermore
265	University of California, Los Angeles
266	University of California, San Francisco
267	University of Chicago Radiation Laboratory
268	University of Puerto Rico
269	University of Rochester (Atomic Energy Project)
270	University of Rochester (Marshak)
271	University of Utah
272	University of Washington (Geballe)

273	University of Washington (Rohde)
274	Western Reserve University (Friedell)
275	Western Reserve University (Major)
276-279	Westinghouse Bettis Atomic Power Laboratory
280	Westinghouse Electric Corporation (Rahilly)
281	Westinghouse Electric Corporation (NASA)
282	Yankee Atomic Electric Company
283-307	Technical Information Service, Oak Ridge

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308-350	USNRDL, Technical Information Division

DISTRIBUTION DATE: 1 November 1962

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USNRDL-TR-586
A PORTABLE COMBINATION DOSE-DOSERATE METER by R.L. Hopton 1 October 1962 27 p. illus. 5 refs. UNCLASSIFIED

A battery-operated portable combination ratemeter-dosimeter has been developed which will measure gamma radiation rate from 0-1000 r/hr in three linear decade ranges. Simultaneously, the integrated dose may be read from a digital display whose range is 0-999.9 r. The least count on the

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1. Radiation counters - Circuits.
2. Radiation counters - Design.
3. Gamma counters - Development.
4. Dosimeters - Development.

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II. Title.
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